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THE NATIONAL IGNITION FACILITY: A NEW ERA IN HIGH ENERGY DENSITY SCIENCE

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ABSTRACT

The National Ignition Facility, the world's most energetic laser system, is now operational. This talk will describe NIF, the ignition campaign, and new opportunities in fusion energy and high energy density science enabled by NIF.

THE NATIONAL IGNITION FACILITY

The National Ignition Facility (NIF) is the U.S. Department of Energy (DOE) national center to study inertial confinement fusion (ICF) and high energy density (HED) science at conditions of over 100 million degrees, 100 billion atmospheres and specific densities over 1000. The 192-beam football stadium-sized NIF is now operational at Lawrence Livermore National Laboratory (LLNL). NIF is the most complex optical instrument ever constructed, with over 38,000 large and small optics and 60,000 points controlled by two million lines of software. The NIF Lasers system is designed to produce 1.8 megajoules of energy driven with 351 nm of ultraviolet light using nanosecond pulse lengths. A total 192-beam energy of 1.1 MJ has been demonstrated; this is approximately 30 times more energy than ever produced in an ICF laser system. Nearly 3000 companies have participated in the construction of NIF, the largest scientific project ever constructed by the DOE.

NIF's 192 beams will be directed into a 10-meter-diameter, high-vacuum target chamber containing a centimeter-scale cylindrical hohlraum target. The laser interaction with the hohlraum will produce a radiation field with temperatures of several hundreds eV. The resulting hohlraum conditions will provide the necessary environment to explore a wide range of HED science experiments, including laboratory-scale thermonuclear ignition and burn. Sophisticated diagnostic instruments needed to understand the interaction between the laser and target, such as x-ray and neutron spectrometers, microscopes, and streak cameras, will be mounted around the equator and at the poles of the target chamber.

NIF, a cornerstone of the U.S. Stockpile Stewardship Program (SSP), will execute the HED science experiments necessary to ensure a safe, secure, and reliable nuclear weapon stockpile without underground testing. It will enable the study of fusion energy science with the capability to provide limitless carbon-free energy and will create conditions allowing scientists to study astrophysical conditions never before attainable on earth.

THE NATIONAL IGNITION CAMPAIGN

A major goal of NIF is the demonstration of ignition—net energy production from thermonuclear fusion. NIF ignition experiments will use a centimeter-scale hohlraum containing a millimeter-scale thin-walled plastic or beryllium capsule filled with a mix of deuterium and tritium. Compression of the capsule by the ~280-eV radiation field in the ignition hohlraum drives the deuterium-tritium fuel to conditions under which it will ignite and burn, liberating more energy than is required to initiate the fusion reactions. NIF is designed to achieve target temperatures of 100 million K, radiation temperature over 3.5 million K, density of 1,000 g/cm^3 and 100 billion times atmospheric pressure. These conditions have never been created in a laboratory and exist naturally only in the interiors of the stars and during thermonuclear burn.

The NIF ignition program is being executed via the National Ignition Campaign (NIC), a national effort that includes General Atomics (GA), LLNL, Los Alamos National Laboratory (LANL), and the University of Rochester Laboratory for Laser Energetics (LLE). The primary goal of NIC is to perform credible ignition experiments on the NIF beginning in late FY2010. The scope for NIC includes the ignition physics program as well as development of the diagnostics, targets, target cryogenic system, phase plates and other optics, and personnel and environmental protection activities required to execute ignition experiments. Use of ignition targets will begin in 2010. Experiments at other laser facilities such as OMEGA at LLE, Trident at LANL and Jupiter at LLNL are being used to develop and demonstrate tuning, shock timing, laser ablation and the diagnostics techniques needed to achieve ignition.

NIF IGNITION AND INERTIAL FUSION ENERGY

The achievement of ignition at NIF will demonstrate the scientific feasibility of ICF and will likely focus the world's attention on the possibility of an ICF energy option. A1000-MW electrical IFE power plant would require a repetition frequency of 10 Hz and 12% electrical efficiency, based on current expectations of achievable target gain. Fusion energy will thus require the development of lasers, chambers, optical components, and other systems capable of operating at these conditions.

Scientists at LLNL are also investigating the advantages of placing a subcritical fission blanket around the fusion target chamber. This proposal, called LIFE (for Laser Inertial Fusion Energy), would reduce the required fusion gain by a factor of approximately 4-10. The fission fuel could be one of many fissile materials, including thorium to light-water reactor spent nuclear fuel. The LIFE concept's key feature is the use of ICF-generated neutrons to induce fission reactions in this fuel, extracting virtually all its energy content and leaving only a small residue of long-lived actinide waste. The hybrid approach could close the nuclear fuel cycle without the need for chemical separation and reprocessing, while generating thousands of megawatts of carbon-free electricity. Such schemes could also incinerate more than 99 percent of spent reactor fuel and extend the service life of deep geologic repositories by up to a factor of 20.

FUNDAMENTAL HIGH ENERGY DENSITY SCIENCE AT NIF

NIF will provide national and international researchers unparalleled opportunities to explore fundamental astrophysics, planetary physics, hydrodynamics, nonlinear optical physics, and materials science. Examples of fundamental science experiments planned for NIF include investigation of the physics of planetary interiors, the formation of elements with $Z>26$ via Type II supernovae explosions, excited state nuclear reactions, and ultra-intense laser-matter interactions. Numerous other experiments are under active consideration. A call for proposals in fundamental high energy density science at NIF is planned for the August 2009 time frame. NIF will ultimately be a major international center for fundamental high energy density science.

CONCLUSION

NIF is now operational, with ignition experiments expected to begin in FY2010. Ignition at NIF will be a landmark scientific achievement and will open new possibilities for clean, sustainable energy production. NIF will also allow fundamental study of matter at extreme energy densities, including the possibility of examining astrophysical phenomena in the laboratory for the first time. NIF will open a new era in HED science.

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